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N^3LO approximate results for top-quark differential cross sections and forward-backward asymmetry

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I present a calculation of approximate N^3LO corrections from NNLL soft-gluon resummation for differential distributions in top-antitop pair production in hadronic collisions. Soft-gluon corrections are the dominant contribution to top-quark production and closely approximate exact results through NNLO. I show aN^3LO results for the total $t\bar{t}$ cross section, the top-quark p_T and rapidity distributions, and the top-quark forward-backward asymmetry. The higher-order corrections are significant and they reduce theoretical uncertainties.

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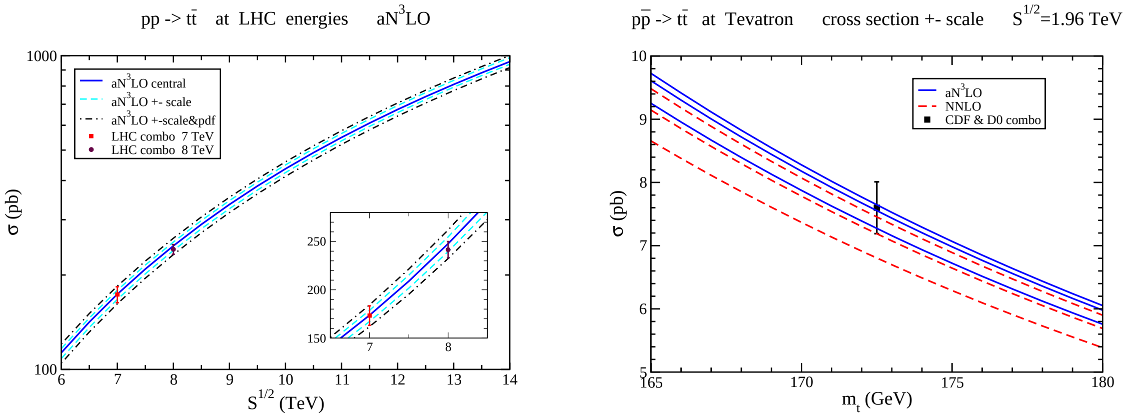


Figure 1: Total aN^{3}LO cross sections for $t\bar{t}$ production at the LHC (left) and the Tevatron (right) and comparison with LHC [7, 8] and Tevatron [9] data.

1. Introduction

The calculation of higher-order corrections for $t\bar{t}$ total cross sections, top-quark transverse momentum (p_T) and rapidity distributions, and the top forward-backward asymmetry ($A_{\rm FB}$) is an important part of top-quark physics. QCD corrections are very significant for top-antitop pair production. Soft-gluon corrections, calculated appropriately, are the dominant part of these corrections at LHC and Tevatron energies. The soft corrections are currently known through N^{3}LO [1–3].

The soft-gluon terms in the nth-order perturbative corrections involve $[\ln^k(s_4/m_t^2)]/s_4$ with $k \le 2n-1$ and s_4 the kinematical distance from partonic threshold. We resum these soft corrections at NNLL accuracy via factorization and renormalization-group evolution of soft-gluon functions [4]. The calculation is for the double-differential cross section using the standard moment-space resummation in perturbative QCD. The first N^{3}LO expansion was given in [5] with a complete formal expression given in [6]. Approximate N^{3}LO (aN^{3}LO) total and differential cross sections from the expansion of the NNLL resummed expressions have been obtained most recently in [1, 2]. The latest aN^{3}LO results for the total cross section [1], top p_T and rapidity distributions [2], and the top forward-backward asymmetry $A_{\rm FB}$ [3], provide the best and state-of-the-art theoretical predictions.

It has been known for some time that the partonic threshold approximation in our formalism works very well for LHC and Tevatron energies; the differences between approximate and exact cross sections at both NLO and NNLO are at the per mille level. This is also true for p_T and rapidity distributions and $A_{\rm FB}$. The use of a fixed-order expansion removes the need for a prescription to deal with divergences and the unphysical effects of such prescriptions. The stability and robustness of the theoretical higher-order results in our resummation approach over the past two decades as well as the correct prediction of the size of the exact NNLO corrections validate our formalism.

2. Top-antitop pair total cross sections at the LHC and the Tevatron

In Fig. 1 we show the aN^{3}LO total $t\bar{t}$ cross sections at LHC and Tevatron energies [1] and

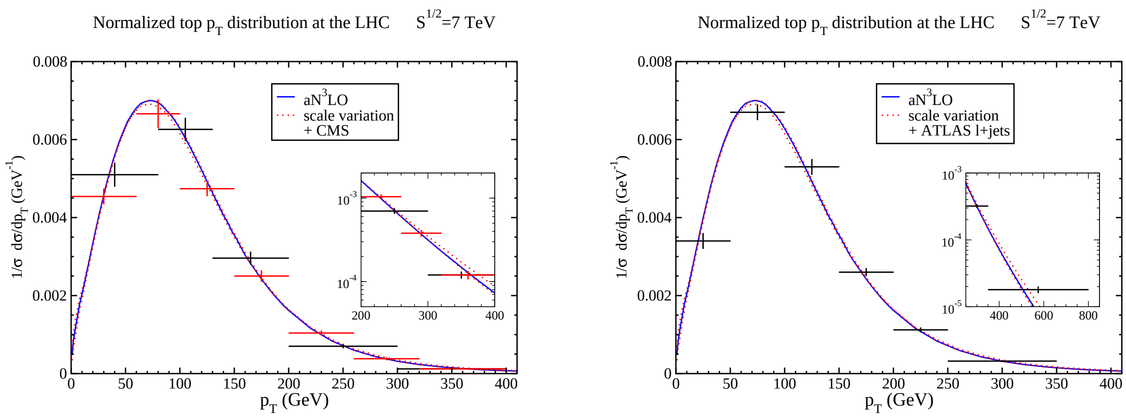


Figure 2: Normalized aN^{3}LO top-quark p_T distributions at the 7 TeV LHC, and comparison with CMS data [11] in the dilepton (black) and lepton+jets (red) channels (left plot), and with ATLAS data [12] in the lepton+jets channel (right plot).

compare them with LHC combination data from the ATLAS and CMS collaborations at 7 TeV [7] and 8 TeV [8] energies, and Tevatron combination data from the CDF and D0 collaborations at 1.96 TeV energy [9]. We use MSTW2008 NNLO pdf [10] for all our predictions. The agreement of theoretical predictions with experimental data is excellent.

We also provide the aN^{3}LO total $t\bar{t}$ cross sections with $m_t = 173.3$ GeV below. At the Tevatron with 1.96 TeV energy the cross section is $7.37^{+0.09}_{-0.27}{}^{+0.38}_{-0.28}$ pb; at the 7 TeV LHC it is $174^{+5}_{-7}{}^{+9}_{-10}$ pb; at the 8 TeV LHC it is $248^{+7}_{-8}{}^{+12}_{-13}$ pb; at the 13 TeV LHC it is $810^{+24}_{-16}{}^{+30}_{-32}$ pb; and at the 14 TeV LHC it is $957^{+28}_{-19}{}^{+34}_{-36}$ pb. The first uncertainty in the previous numbers is from scale variation over $m_t/2 \le \mu \le 2m_t$ and the second is from the MSTW2008 pdf [10] at 90% C.L.

Fractional contributions to the perturbative series for the $t\bar{t}$ cross section at the LHC converge well through N^{3}LO, which could potentially indicate that corrections beyond N^{3}LO are negligible [1]. For Tevatron energies the convergence is slower [1].

3. Top-quark p_T and rapidity distributions at the LHC and the Tevatron

In Fig. 2 we show the normalized aN^{3}LO top-quark p_T distribution, $(1/\sigma)d\sigma/dp_T$, at 7 TeV LHC energy and compare with results from CMS in the dilepton and lepton+jets channels [11] and from ATLAS in the lepton+jets channel [12]. We find excellent agreement between the theoretical results and the 7 TeV LHC data. The theoretical predictions are also in excellent agreement with recent CMS top p_T data at 8 TeV in both channels [13].

In the left plot of Fig. 3 we show the aN^{3}LO top-quark p_T distributions [2], $d\sigma/dp_T$, at 13 and 14 TeV LHC energies. In the right plot of Fig. 3 we show the aN^{3}LO top-quark p_T distributions [2] at 1.96 TeV Tevatron energy and compare with D0 data [14], finding very good agreement.

We continue with the top-quark rapidity distribution at the LHC [2]. In the left plot of Fig. 4 we show the normalized aN^{3}LO top-quark rapidity distribution, $(1/\sigma)d\sigma/dY$, at 7 TeV LHC energy and compare with results from CMS in the dilepton and lepton+jets channels [11], finding excellent agreement between theory and data. The theoretical predictions at 8 TeV are also in

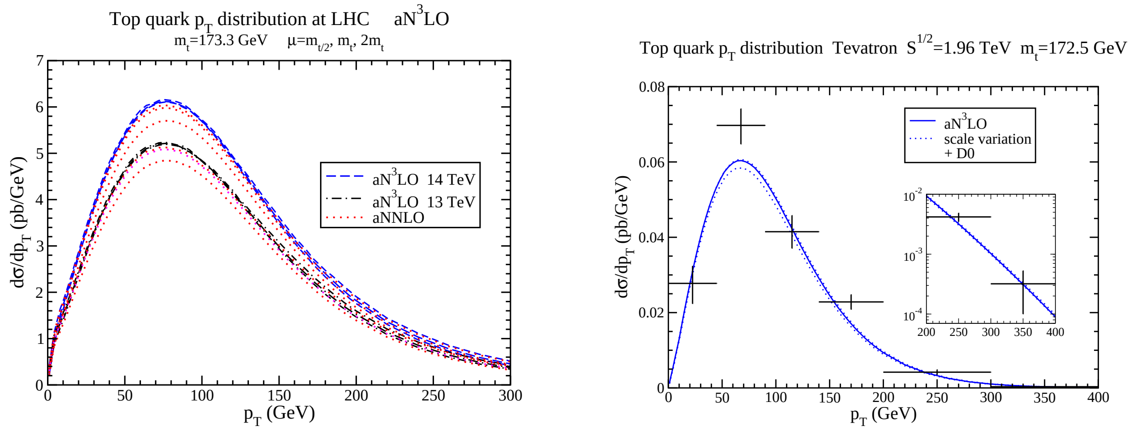


Figure 3: Top-quark aN^{3}LO p_T distributions at the LHC (left) and at the Tevatron compared to D0 data [14] (right).

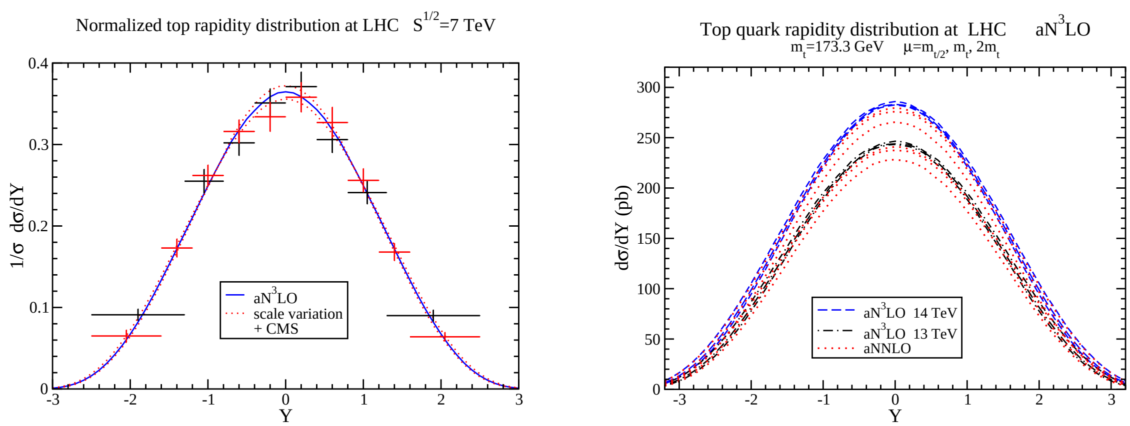


Figure 4: (Left) Top-quark aN^{3}LO normalized rapidity distributions at the 7 TeV LHC and comparison with CMS data [11] in the dilepton (black) and lepton+jets (red) channels; (Right) Top-quark aN^{3}LO rapidity distributions at 13 and 14 TeV LHC energies.

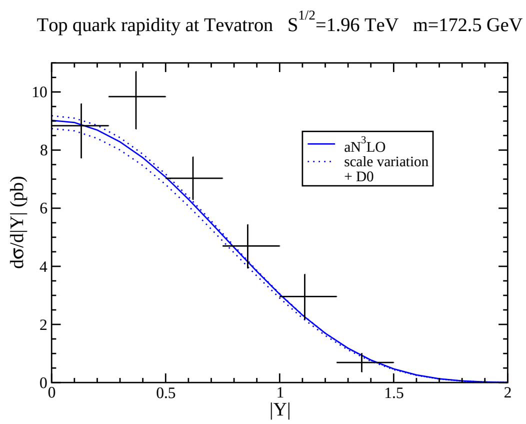
excellent agreement with recent CMS top rapidity data in both channels [13]. We also show the aN^{3}LO top-quark rapidity distributions, $d\sigma/dY$, at 13 and 14 TeV LHC energies in the right plot of Fig. 4.

In the left plot of Fig. 5 we compare the aN^{3}LO distribution of the absolute value of the top-quark rapidity, $d\sigma/d|Y|$, at the Tevatron with D0 data [14] and find very good agreement.

4. Top-quark forward-backward asymmetry at the Tevatron

Finally, we discuss the top forward-backward asymmetry at the Tevatron

$$A_{\rm FB} = \frac{\sigma(y_t > 0) - \sigma(y_t < 0)}{\sigma(y_t > 0) + \sigma(y_t < 0)} \, . \tag{4.1}$$



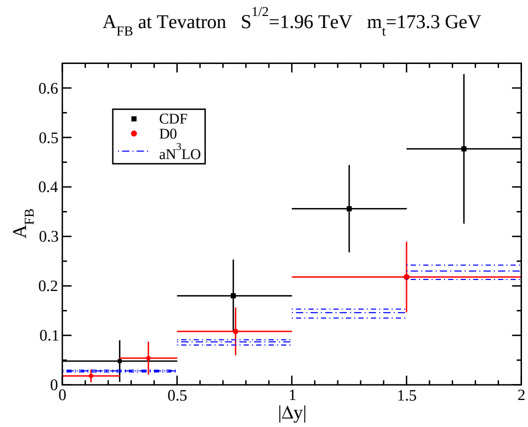


Figure 5: (Left) Top-quark aN^{3}LO $d\sigma/d|Y|$ distribution at the Tevatron compared with D0 data [14]; (Right) Top-quark aN^{3}LO differential $A_{\rm FB}$ at the Tevatron compared with CDF [16] and D0 [17] data.

The above expression can be evaluated with numerator and denominator separately at fixed-order or it can be re-expanded in α_s (see [3] for details through aN^{3}LO). As was discussed in [3] the soft-gluon corrections are dominant and in our formalism they precisely predicted [15] the exact asymmetry at NNLO. The high-order perturbative corrections are large: the aN^{3}LO/NNLO ratio is 1.08 without re-expansion in α_s, or 1.05 with re-expansion in α_s. Including electroweak corrections and the aN^{3}LO QCD corrections we find an asymmetry of (10.0 ± 0.6)% in the $t\bar{t}$ frame using re-expansion in α_s.

The differential top forward-backward asymmetry is defined by

$$A_{\rm FB}^{\rm bin} = \frac{\sigma^+_{\rm bin}(\Delta y)-\sigma^-_{\rm bin}(\Delta y)}{\sigma^+_{\rm bin}(\Delta y)+\sigma^-_{\rm bin}(\Delta y)} \quad \text{with} \quad \Delta y = y_t - y_{\bar{t}}\,.$$

In the right plot of Fig. 5 we plot the differential $A_{\rm FB}$ and compare with recent results from CDF [16] and D0 [17]. The agreement between theory and experiment is very good for both the total and the differential asymmetries.

5. Summary

The N^{3}LO soft-gluon corrections for top-antitop pair production are significant and provide the best available theoretical predictions. Results have been presented for the total $t\bar{t}$ cross sections, the top-quark p_T and rapidity distributions, and the top-quark forward-backward asymmetry. The corrections are large at LHC and Tevatron energies and they reduce the theoretical uncertainties from scale variation. There is excellent agreement between aN^{3}LO theoretical predictions and LHC and Tevatron data.

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